Di-photon at 750 GeV (A first read)

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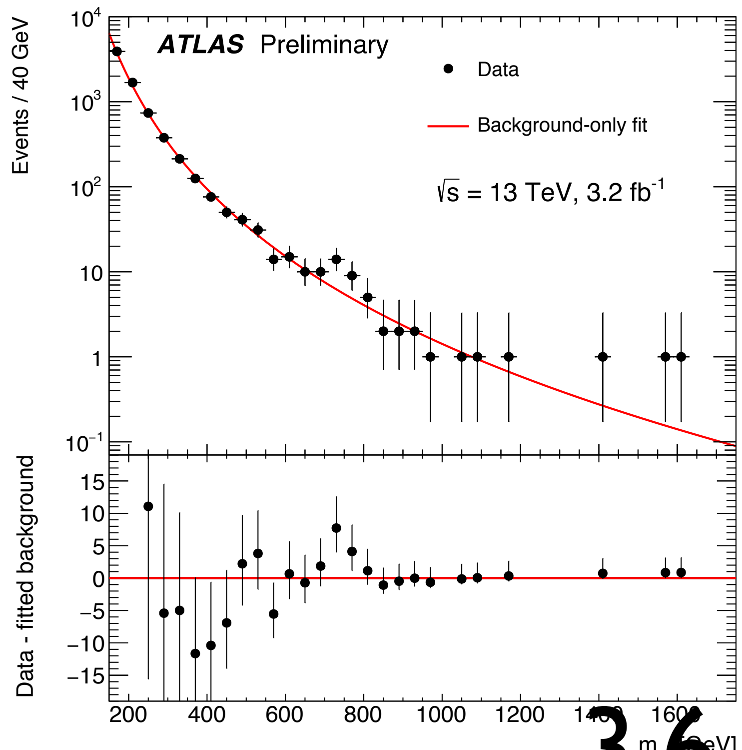
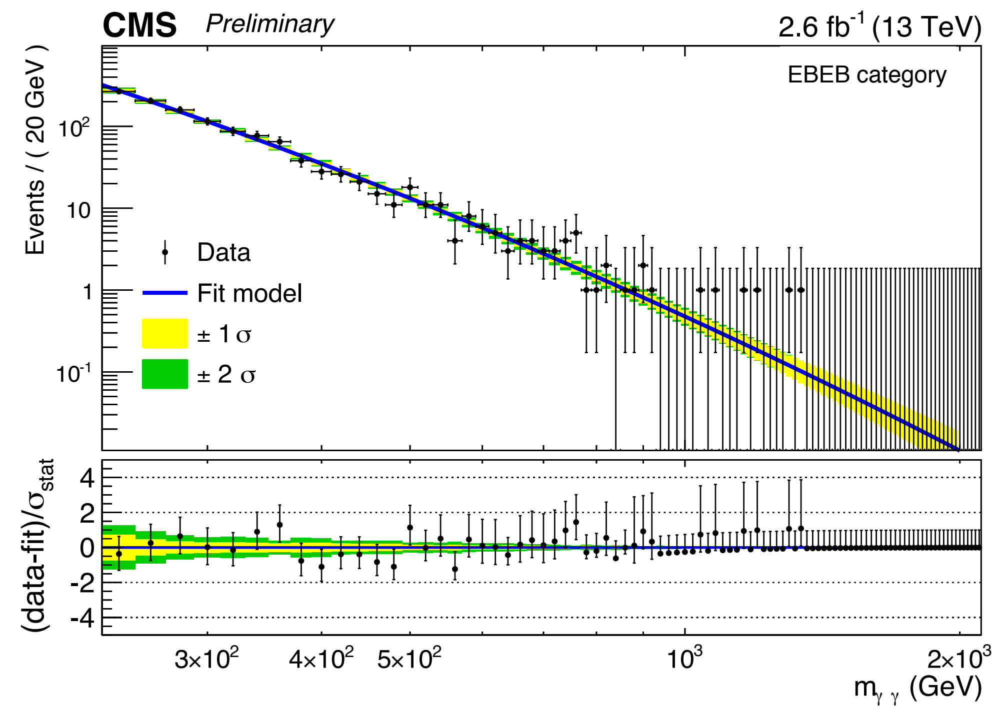
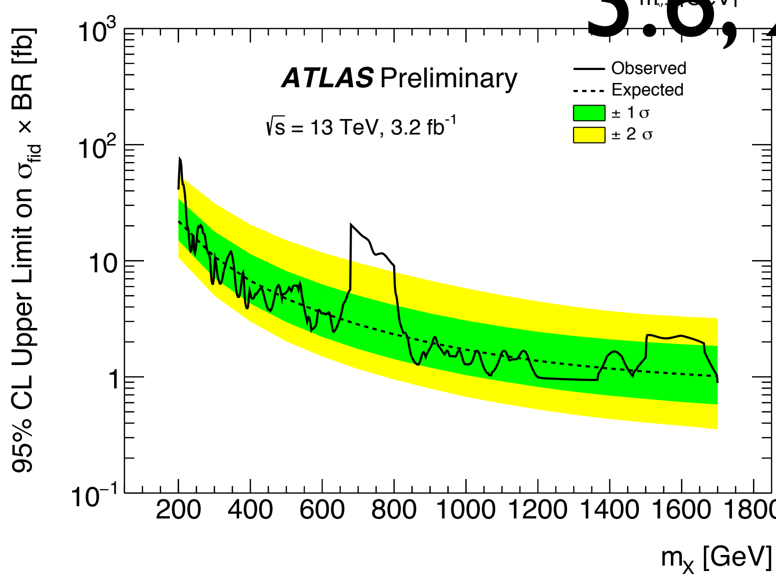
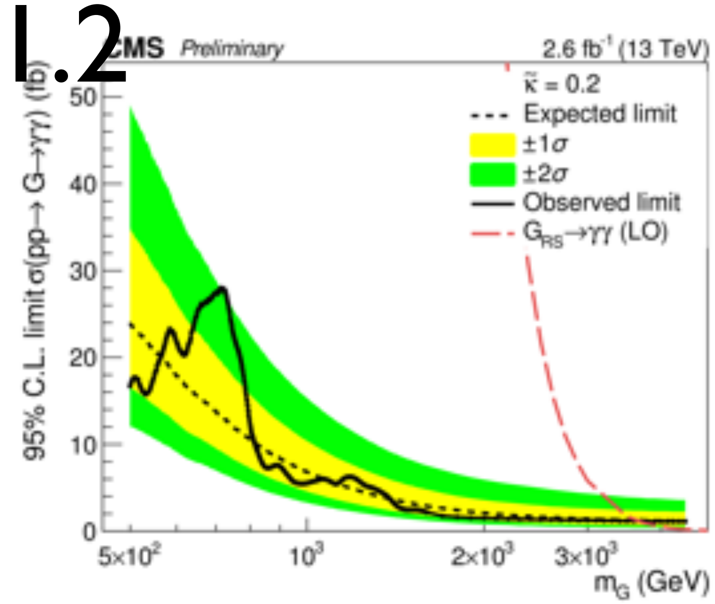
Excess around 750 GeV?





3.6, 2.0 2.6, 1.2





$3.6\sigma(\text{local})$

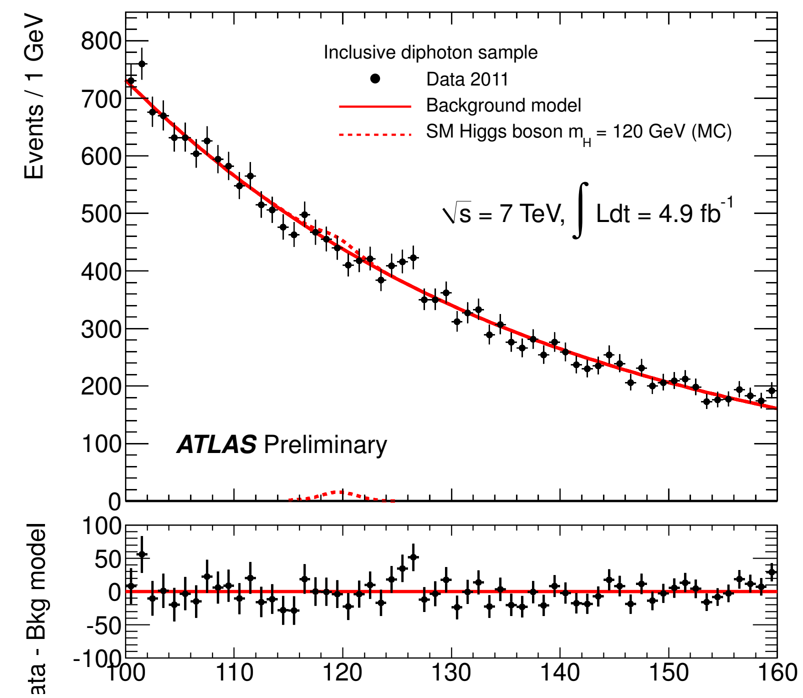
$2\sigma(\text{global})$

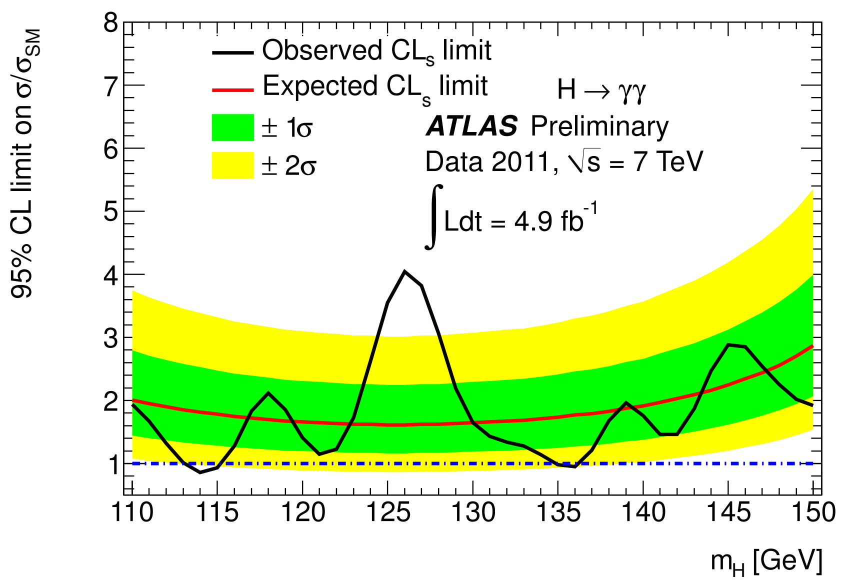
$2.6\sigma(\text{local})$

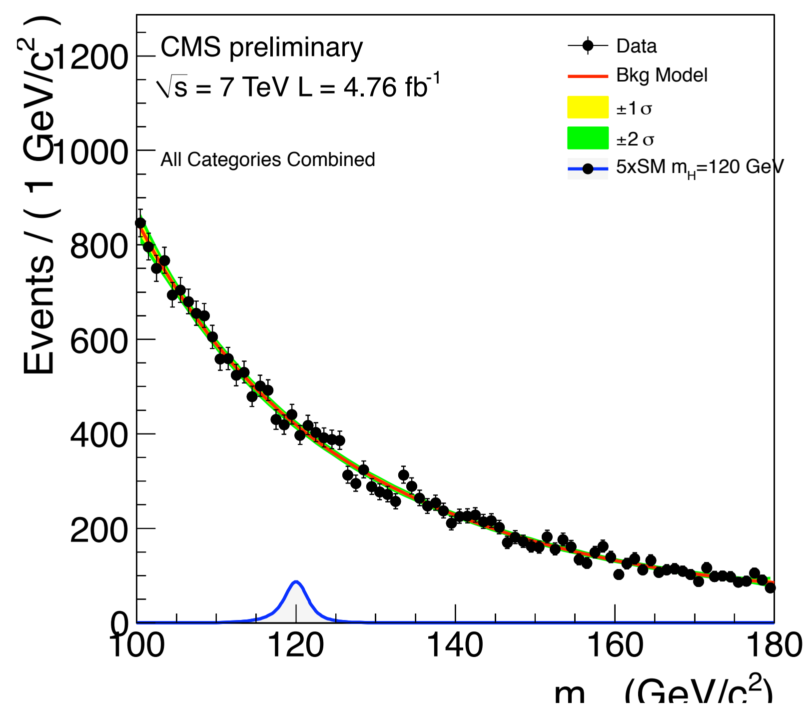
$1.2\sigma(\text{global})$

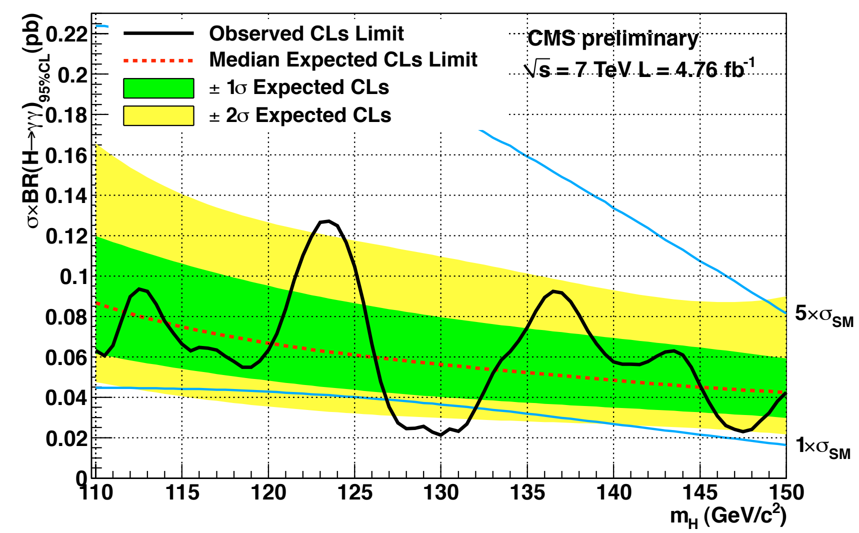
Certainly too early to claim victory. But, tantalizing…

Exactly 4 years ago, $m_{\gamma\gamma} \approx 125$









$2.8\sigma(\text{local})$

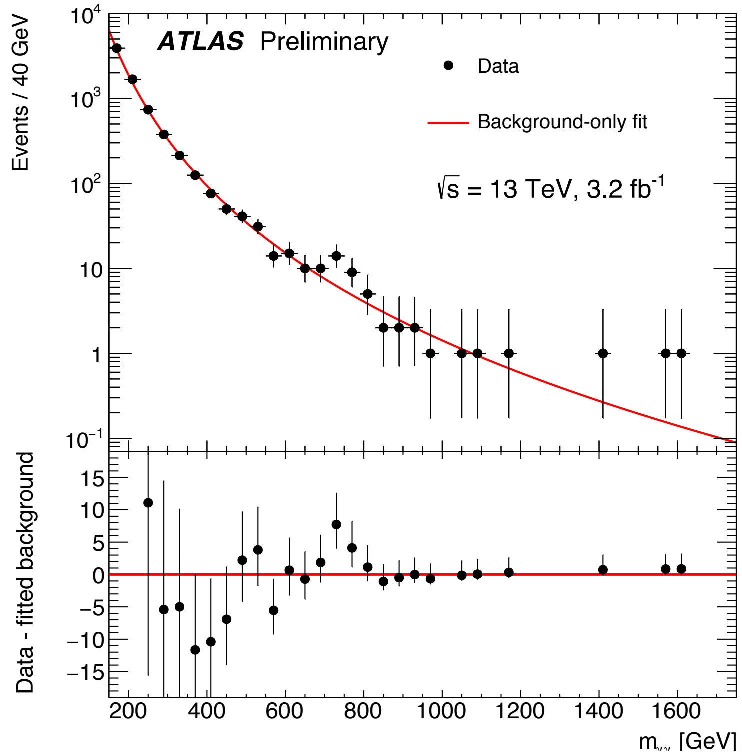
$1.5\sigma(\text{global})$

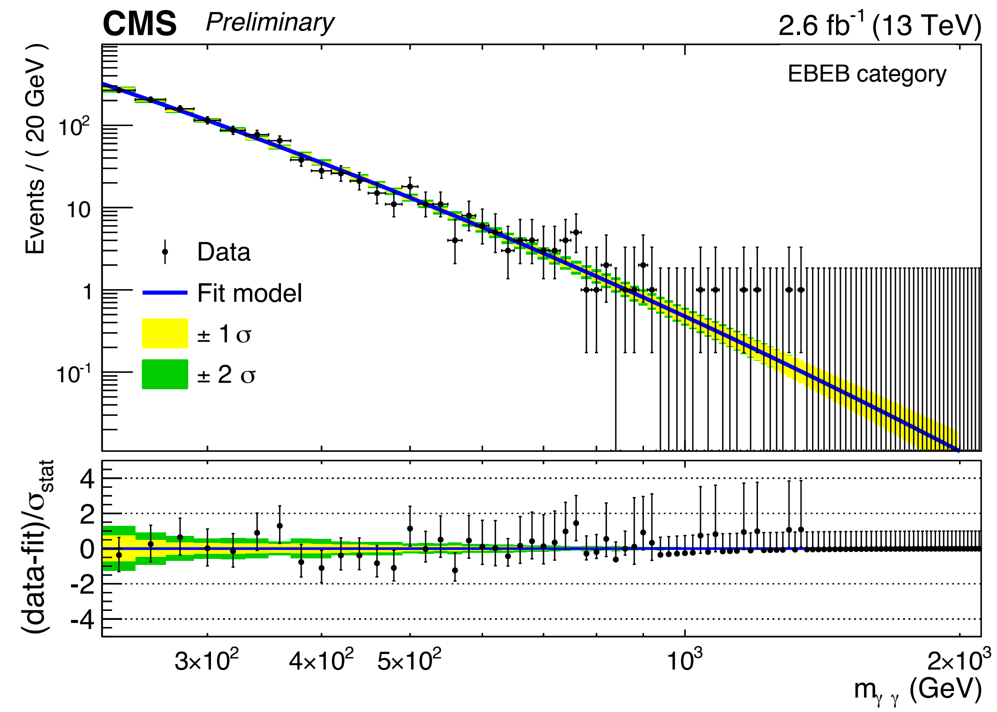
$2.31\sigma(\text{local})$

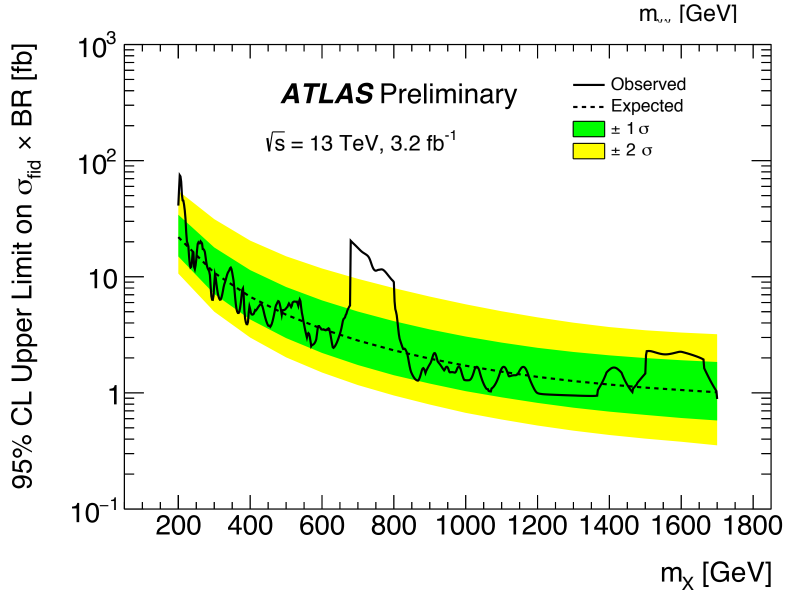
$0.79\sigma(\text{global})$

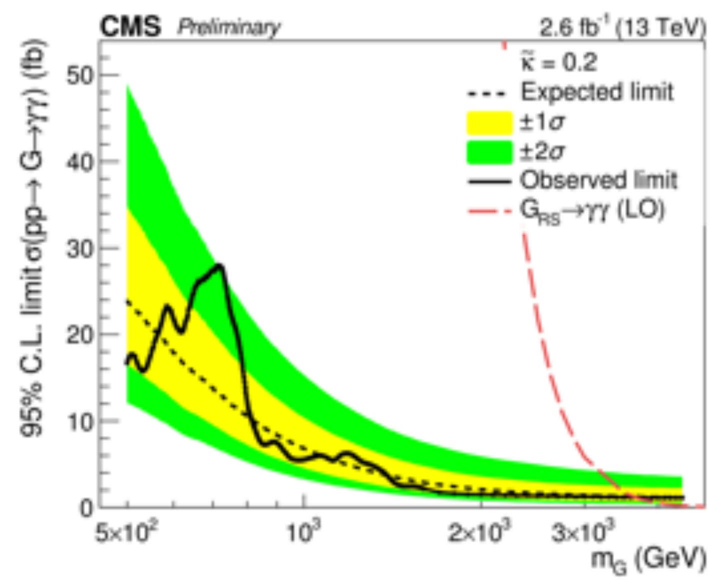
- There is some hope this time too?

Back to 750





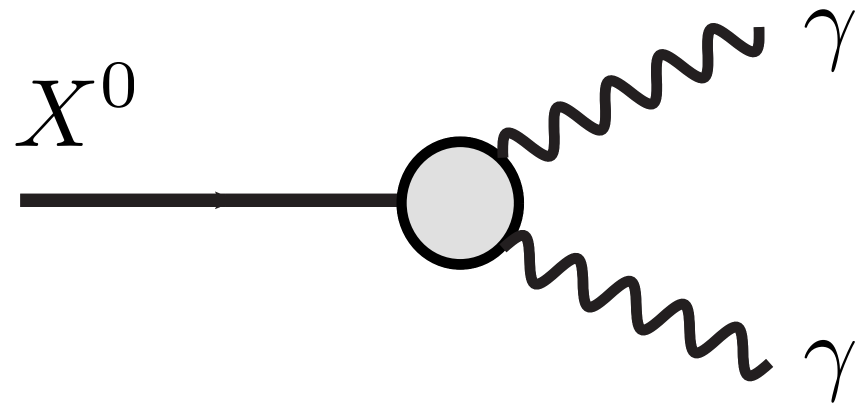




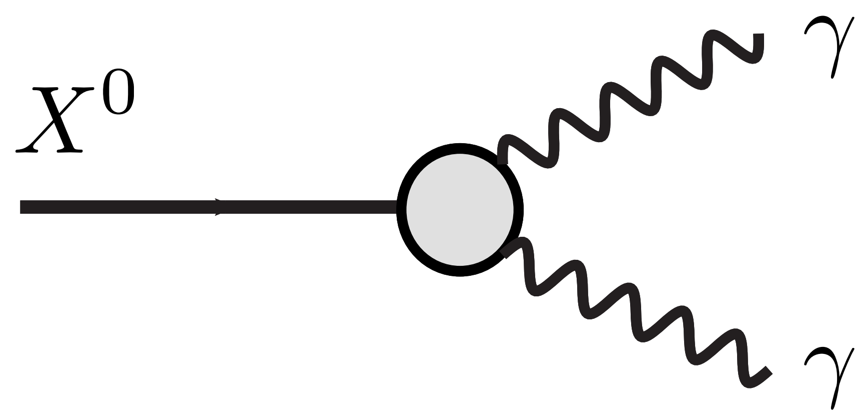
"signal rate": 4-5 fb?

Large. Same order as the SM Higgs to diphoton rate.

Di-photon resonance

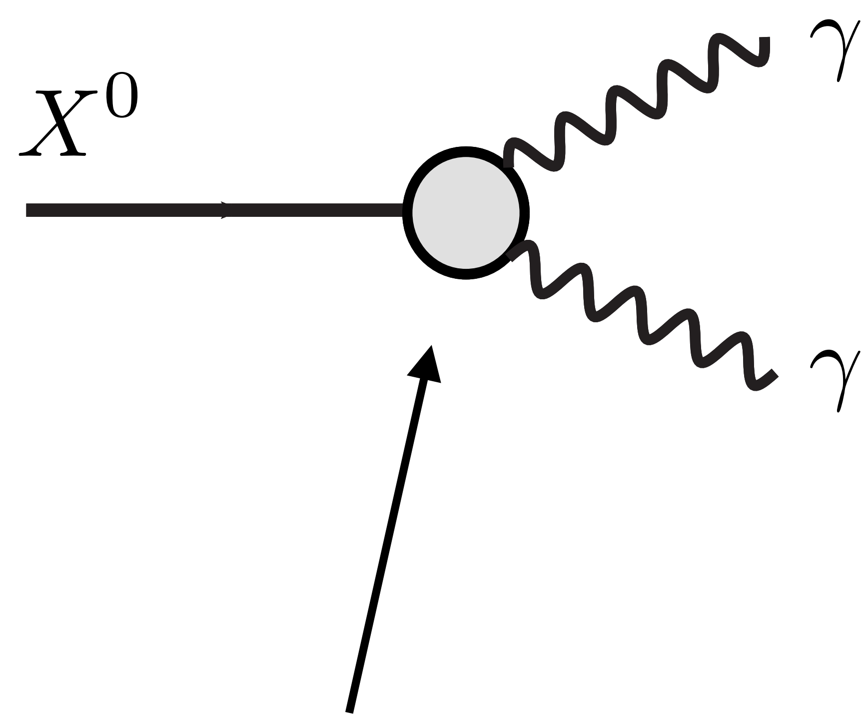


Di-photon resonance



- Can be spin 0 or 2.
  - Not spin-1. Landau-Yang theorem.
  - Completely identical to the argument of the 125 GeV di-photon resonance.
- Spin 0 is much more compelling than spin-2.
  - Very difficult to write down a complete model of spin-2.

How can neutral particle goes to photon, which only couples to charged particles



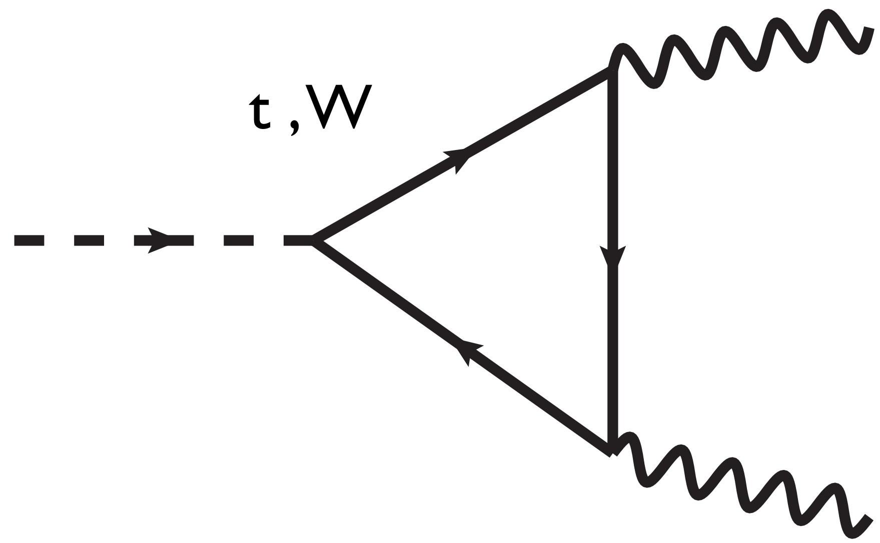
Must be charged particles here.

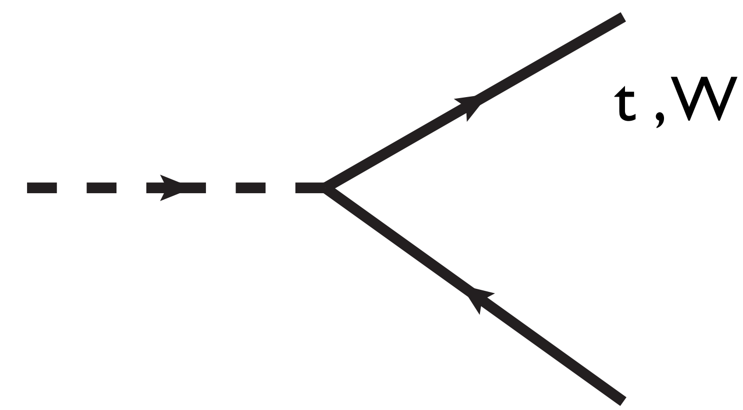
For the SM higgs, they are top quark and W boson

Can top and/or W do it for the X(750)?

No. Can not (just) be top or W.

750 GeV res. can not be alone.
Must have more new physics!!





- Say X couples to top and or W, with arbitrary coupling.
  - BR(di-photon) is less than 10^{-4}.
  - 4 fb to di-photon means 10s -100 pb to ttbar and or WW.
  - A factor of 4 or 5 in the production rates between 8 and 13 TeV.
  - ttbar and/or WW signal of at least pb at 8 TeV.

Possible to have pb(s) level tt or WW resonance at Run 1?

- No.

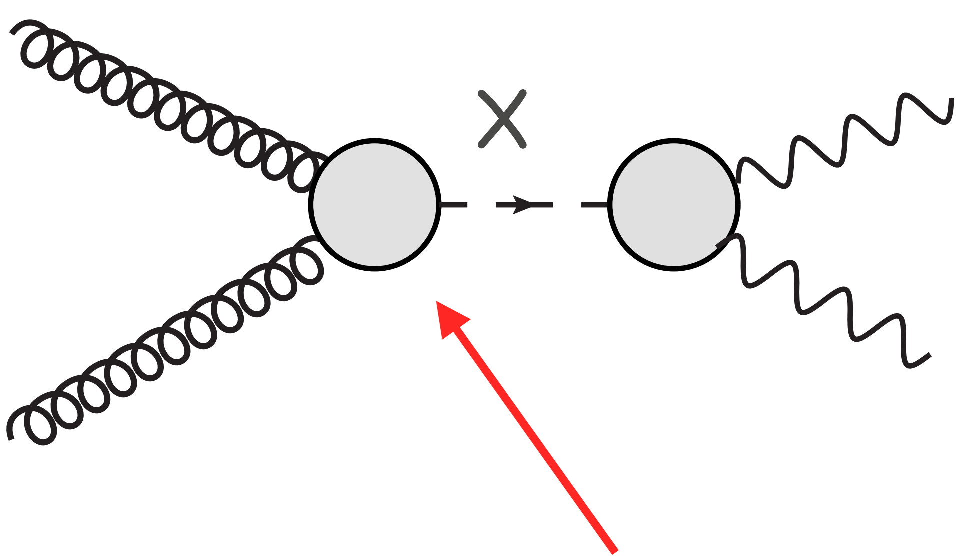
final state	700 GeV	750 GeV	
$t\bar{t}$ (narrow)	540 fb	450 fb	CMS [6]
$t\bar{t}$ (wide)	620 fb	520 fb	CMS [6]
WW ($\ell\nu jj$)	60 fb	70 fb	ATLAS [10]

- Must be more new physics in addition to the 750 GeV resonances!!

Production

- Unlikely from qqbar.
  - Suppressed by small quark masses, otherwise suffer from sever flavor constraints.

- Possibly (like the Higgs)



Need more new physics here as well, colored!

What kind of scalar?

- CP even, real scalar.
  - Typically will mix with the Higgs.
  - More constraining
  - Decays like Higgs with tiny BR to di-photon.
  - Difficult to work.
- CP odd, pseudo-scalar.
  - Much better candidate.

Pseudo-scalar (η) interaction

$$\mathcal{L}_{\rm int} = \frac{y_f}{\Lambda_f}\eta(i\overline{f_L}Hf_R + {\rm h.c.}) + \frac{c_B}{\Lambda_g}\frac{g'^2}{16\pi^2}\eta B_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{c_W}{\Lambda_g}\frac{g^2}{16\pi^2}\eta W^a_{\mu\nu}\tilde{W}^{a\mu\nu} + \frac{c_g}{\Lambda_g}\frac{\alpha_s}{4\pi}\eta G^a_{\mu\nu}\tilde{G}^{a\mu\nu}$$

Pseudo-scalar (η) interaction

with SM top

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anomaly-like

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with SM top — anomaly-like

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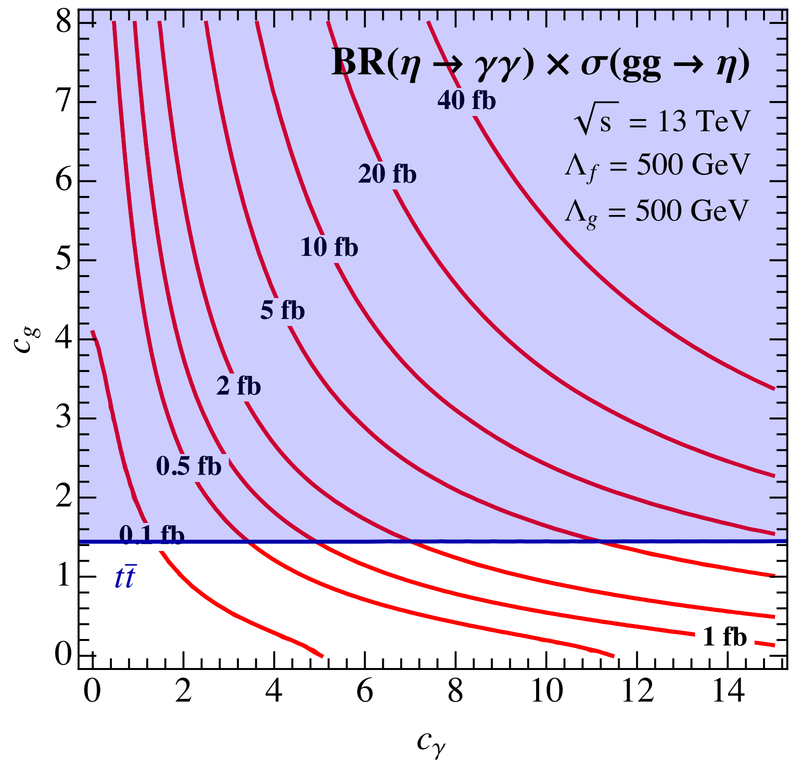
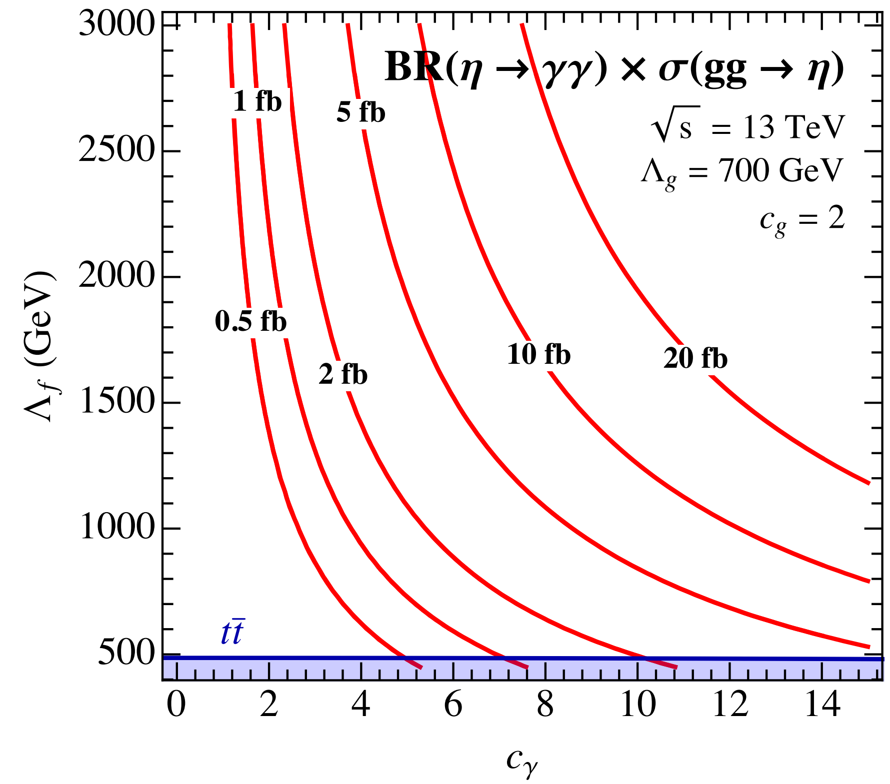
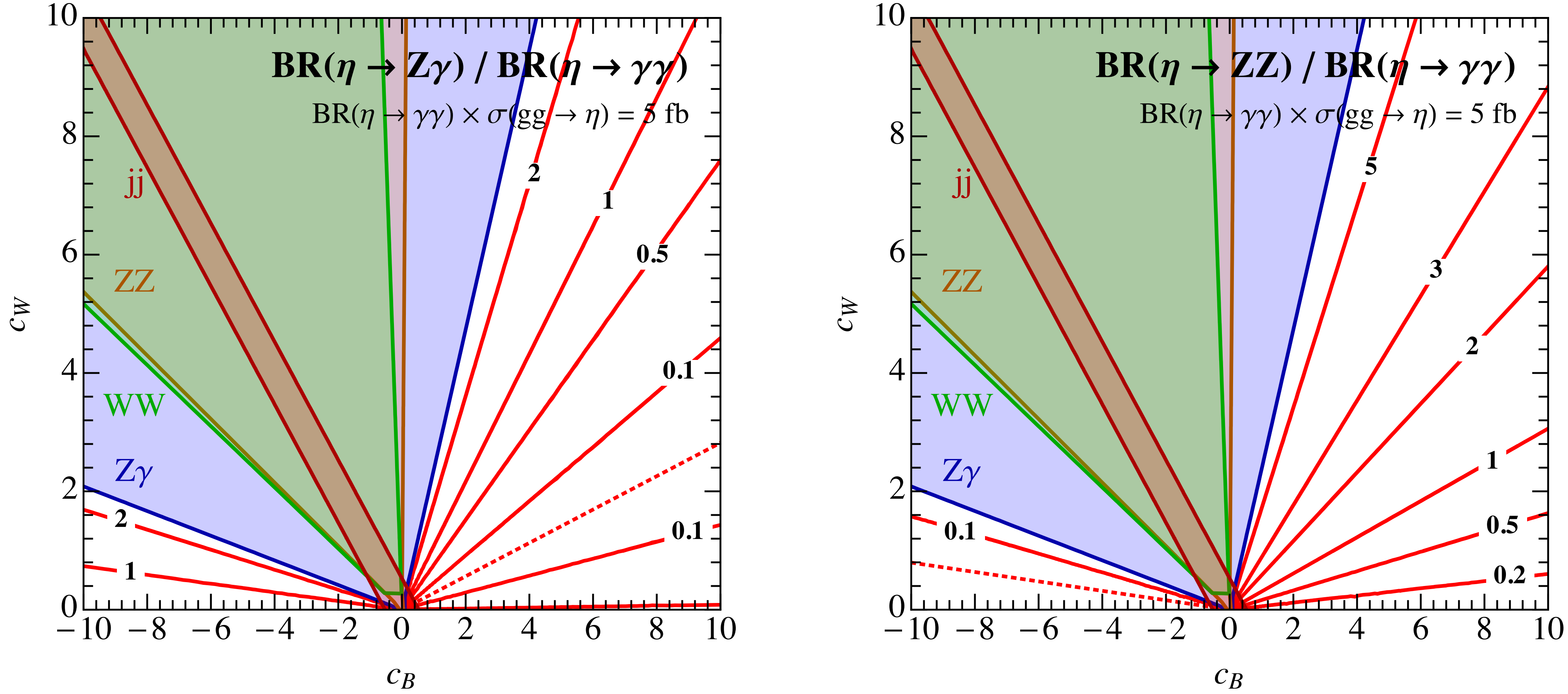




M. Low, A. Tesi, LTW

- Need anomaly contribution for large di-photon BR.
- Will have $Z\gamma$ and ZZ.

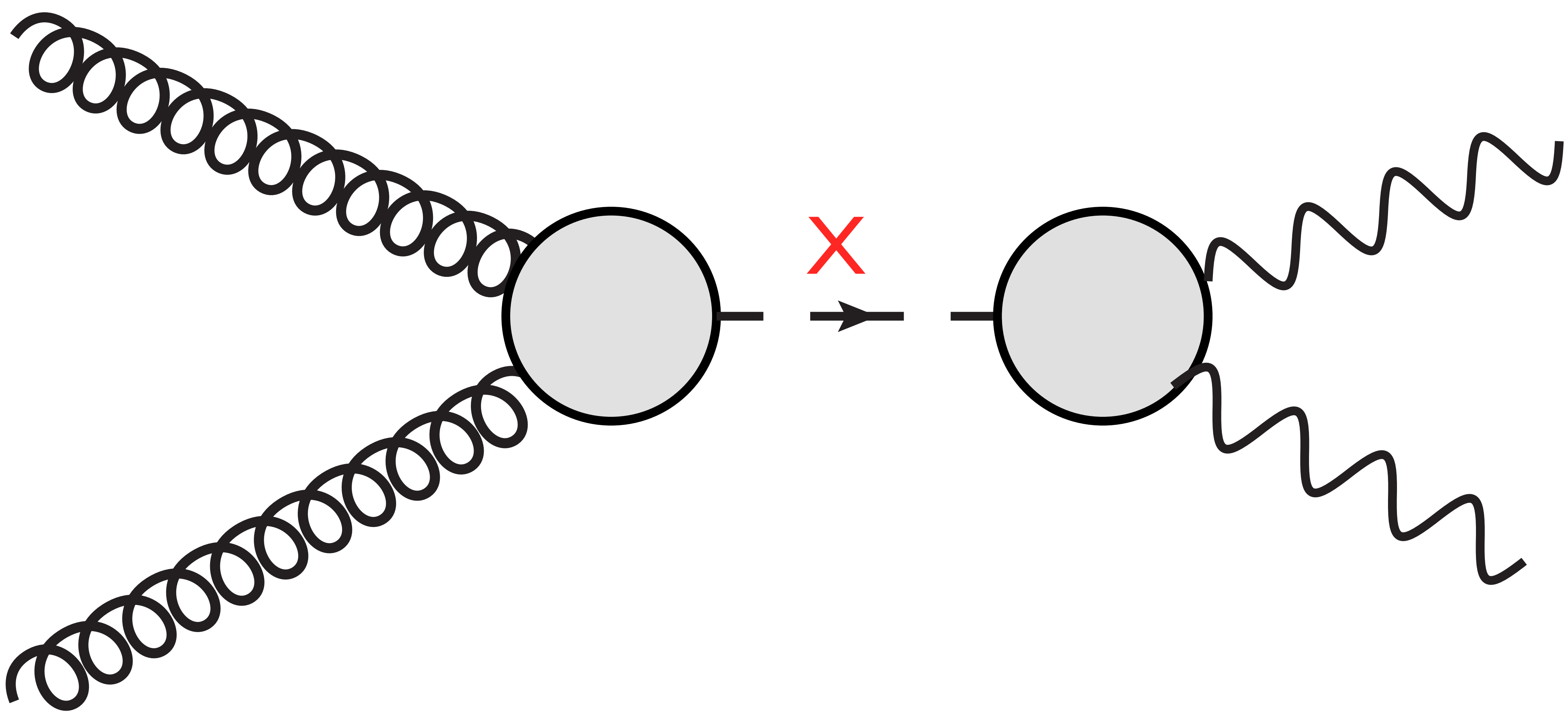
Zγ, ZZ the next things to look for



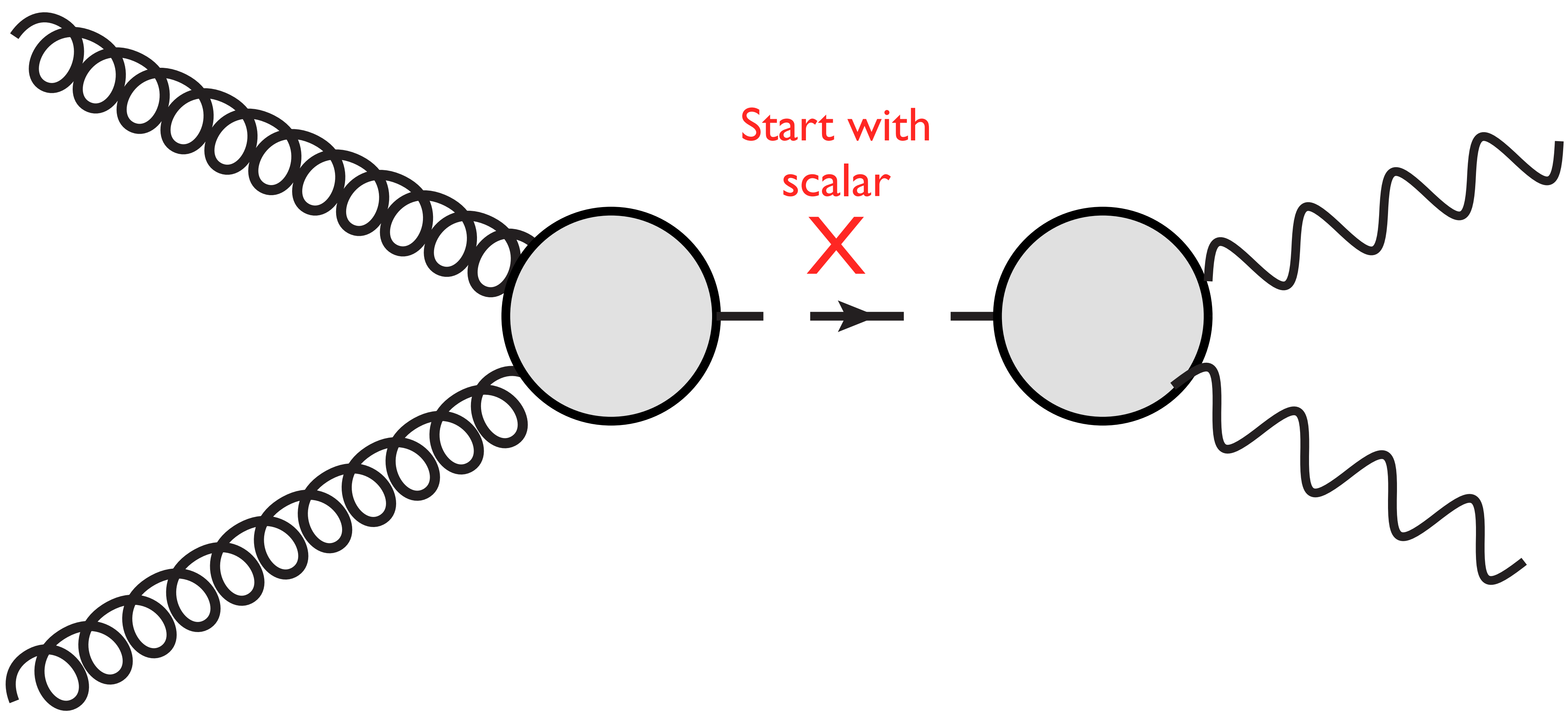
- Also WW, ttbar, hh.
- And everything under 750

NP models

“Simplified” models



"Simplified" models



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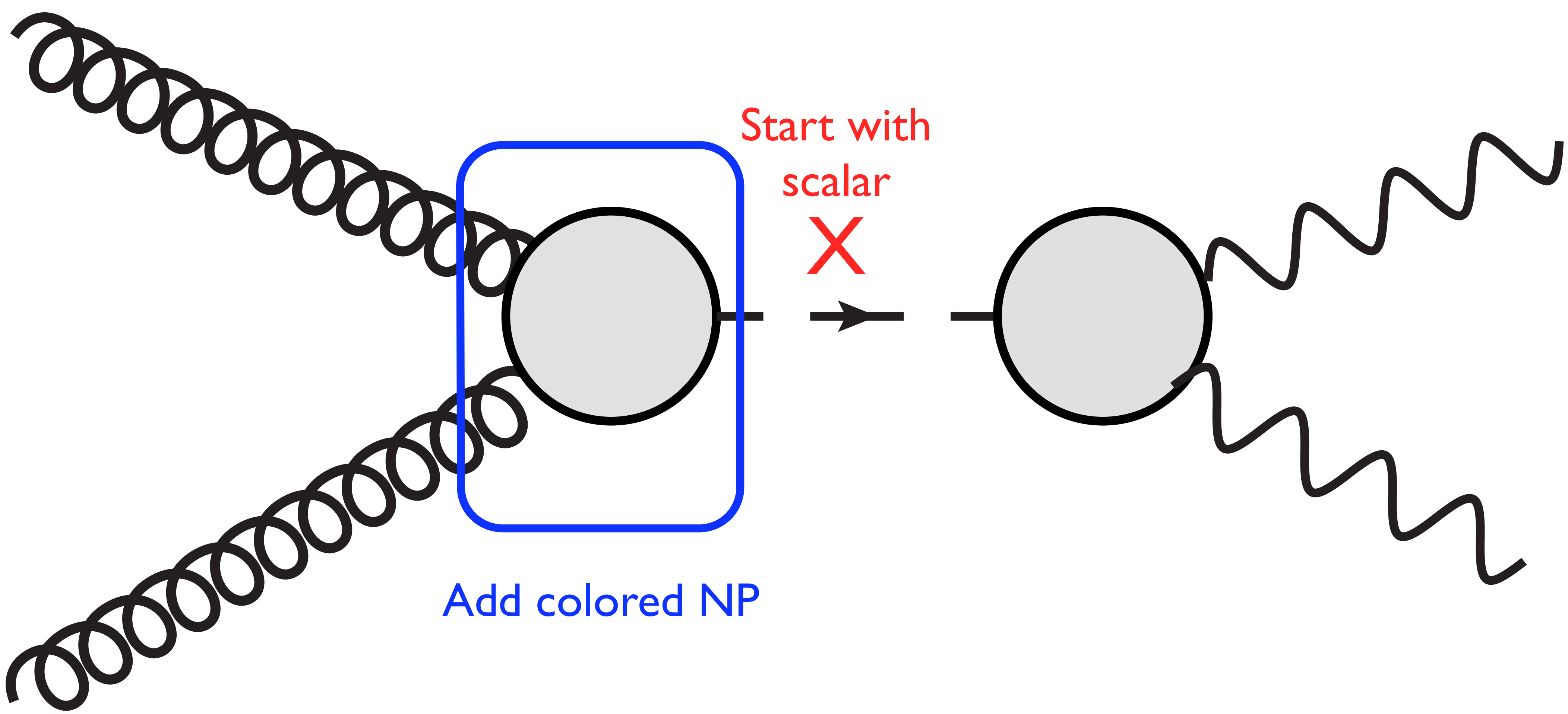

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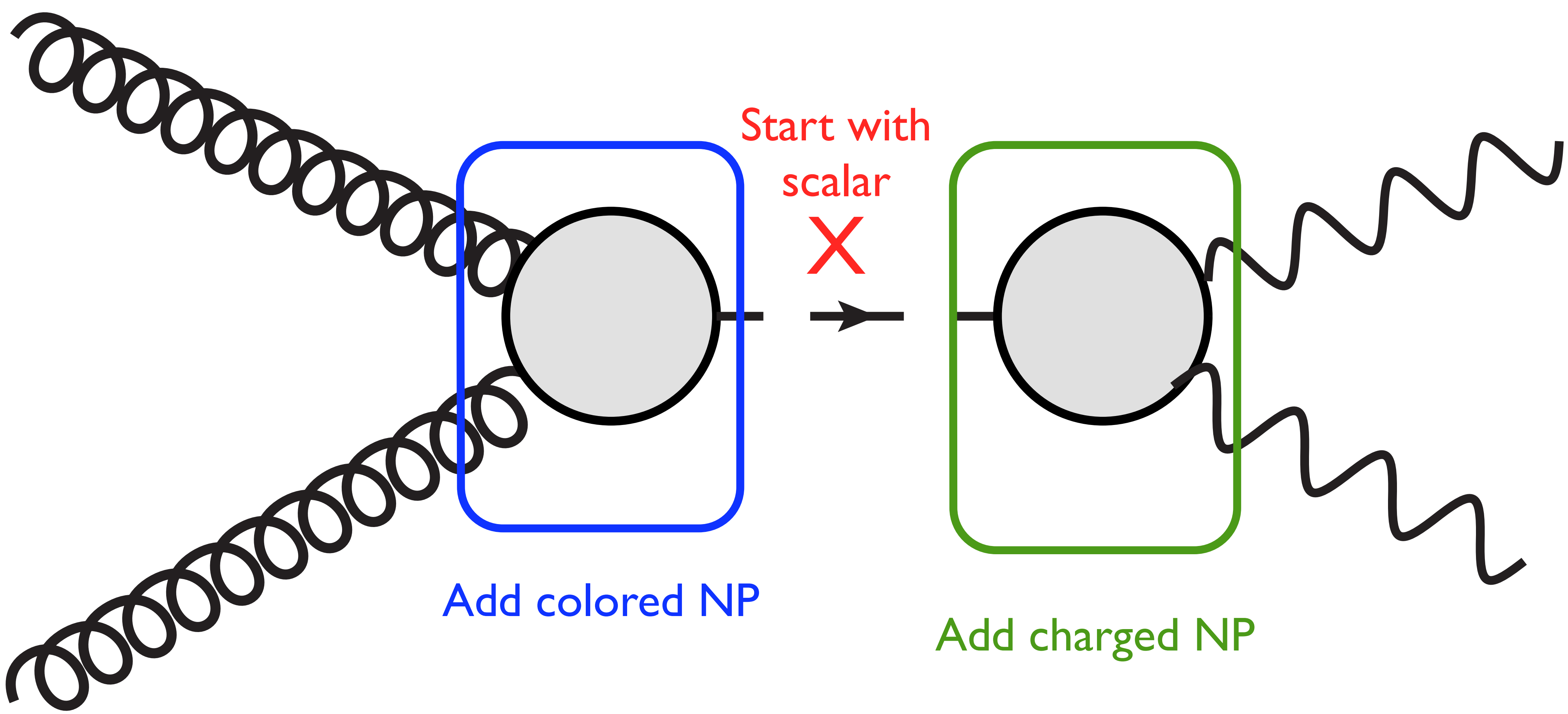

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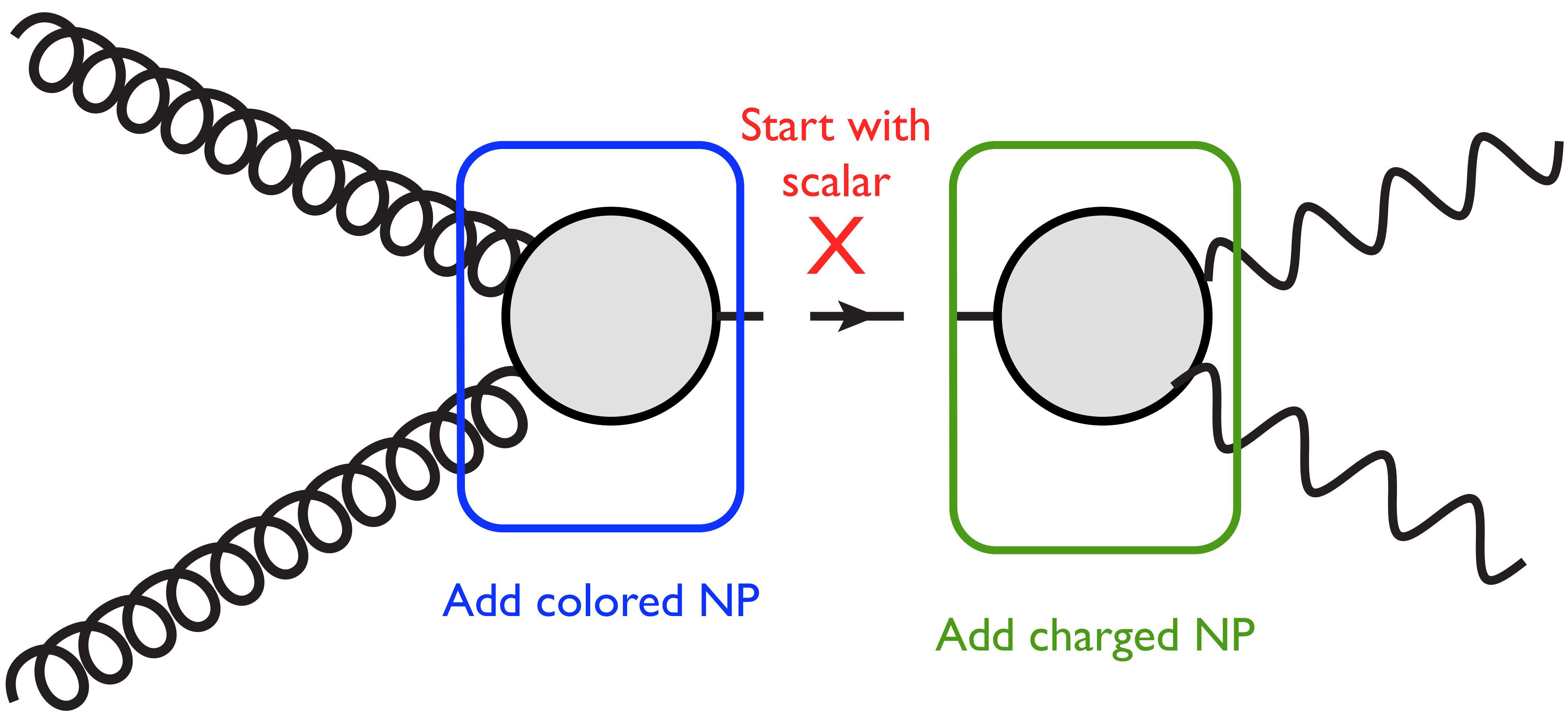

$M_{NP} > 0.5\ M_{X}.$

Vector like fermions.

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  - Can make things much worse.
  - Not controlling weak scale masses in an obvious way. Even landscape may not help.

Mass, why 750 GeV scalar?

- We are already puzzled by m_h (125), naturalness problem.
- Now another (pseudo)scalar?
  - Can make things much worse.
  - Not controlling weak scale masses in an obvious way. Even landscape may not help.
- However, the 750 GeV pseudo-scalar may be the first hint of a natural theory.

Take a page from SM

π^0 DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
2γ	(98.823 ± 0.034) %	S=1.5	67

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TeV(s), resonances

η: 750 GeV

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Λ=10 TeV : new gluon and quarks

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η: 750 GeV

Natural. But mass no relation with weak scale.

Composite Higgs

Λ=10 TeV : new gluon and quarks

m_* ≈TeV(s), resonances

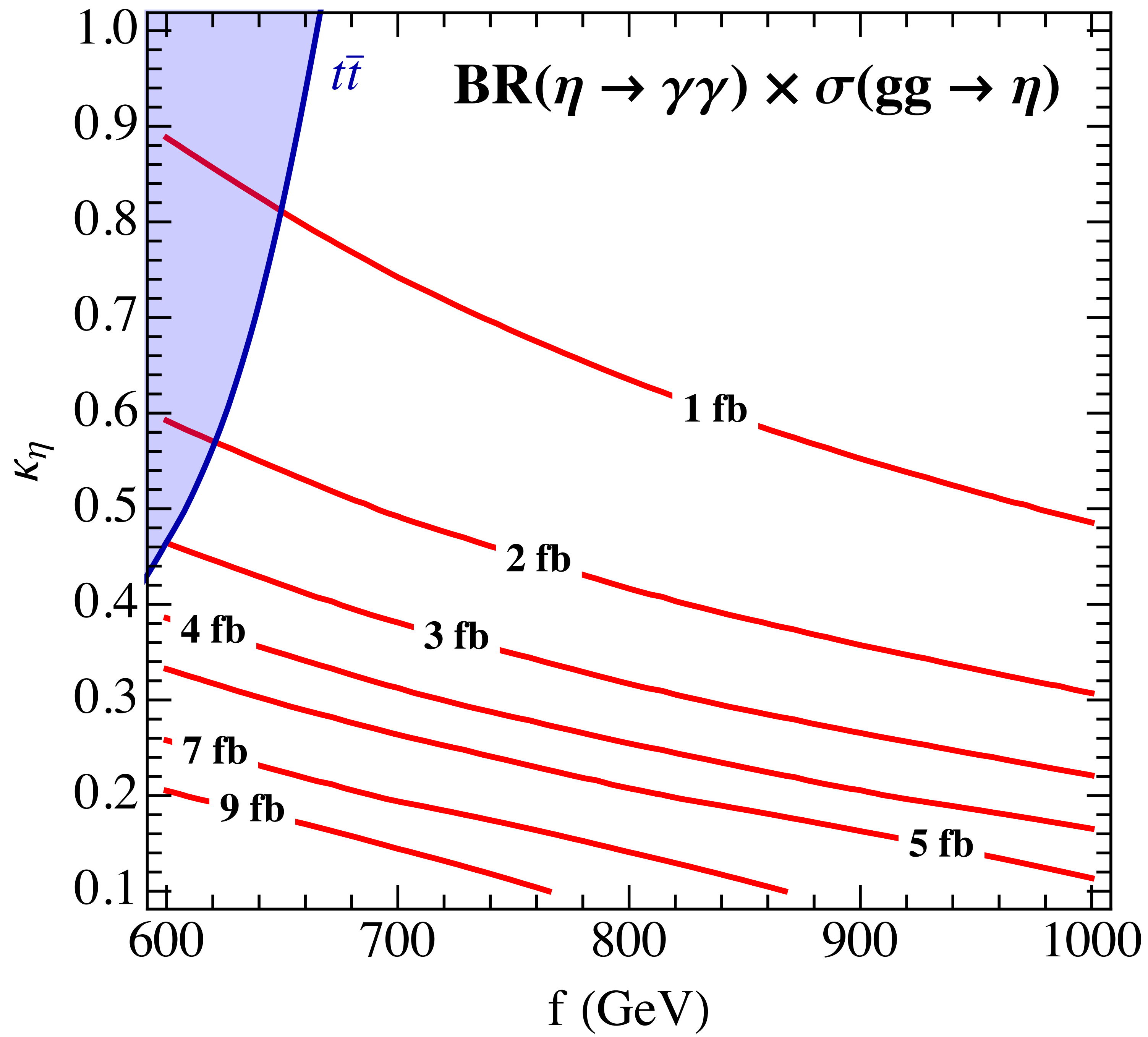
η: 750 GeV

Higgs.

$$m_\eta^2 \simeq \frac{N_c y_t}{2\pi^2}\frac{m_*^3}{f}. \qquad m_\eta \simeq 700\ \text{GeV}\left(\frac{m_*}{1.3\ \text{TeV}}\right)^{3/2}\left(\frac{600\ \text{GeV}}{f}\right)^{1/2}$$

Natural to have 750 with reasonable parameters

Di-photon rate in composite Higgs



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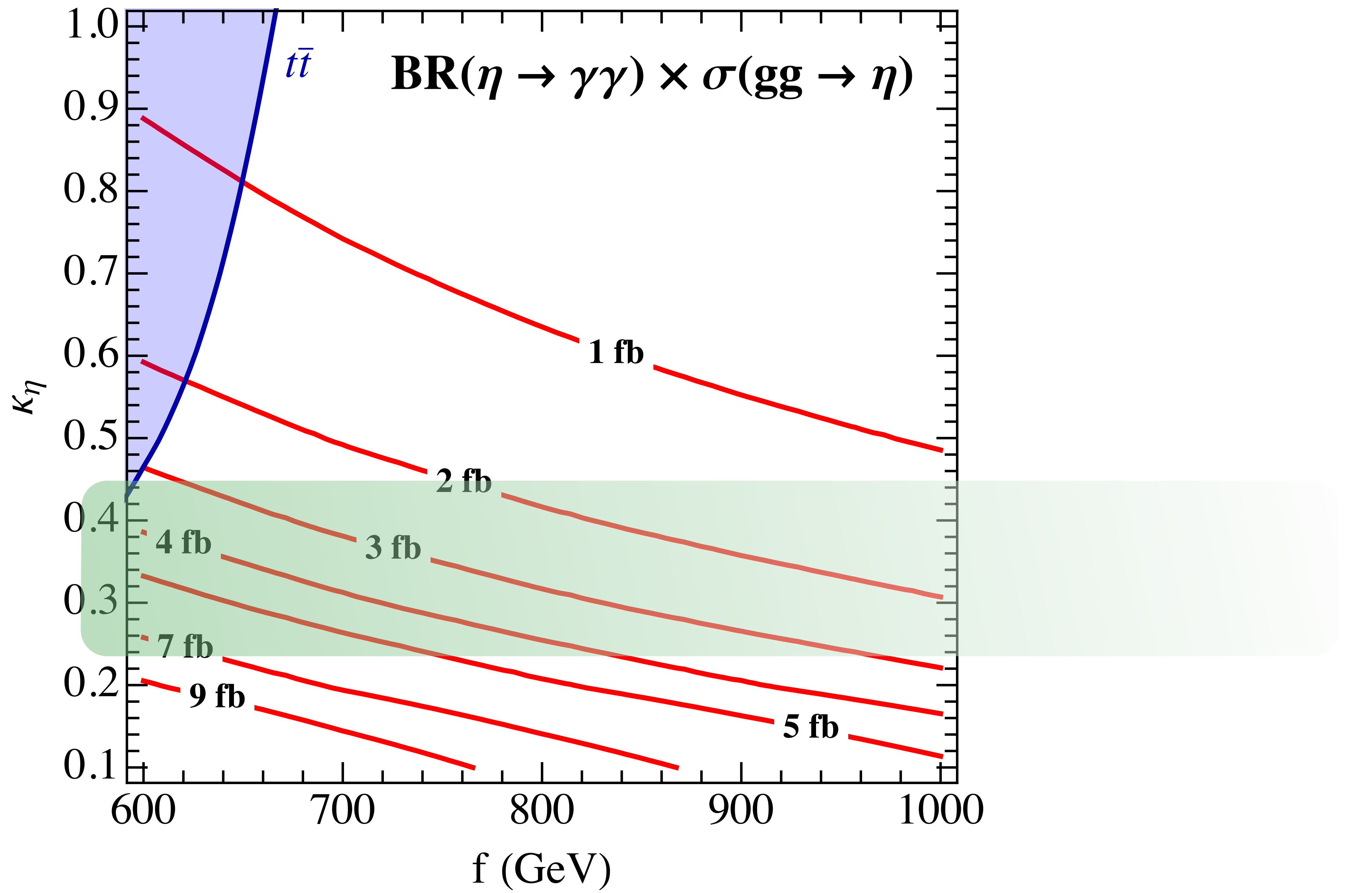
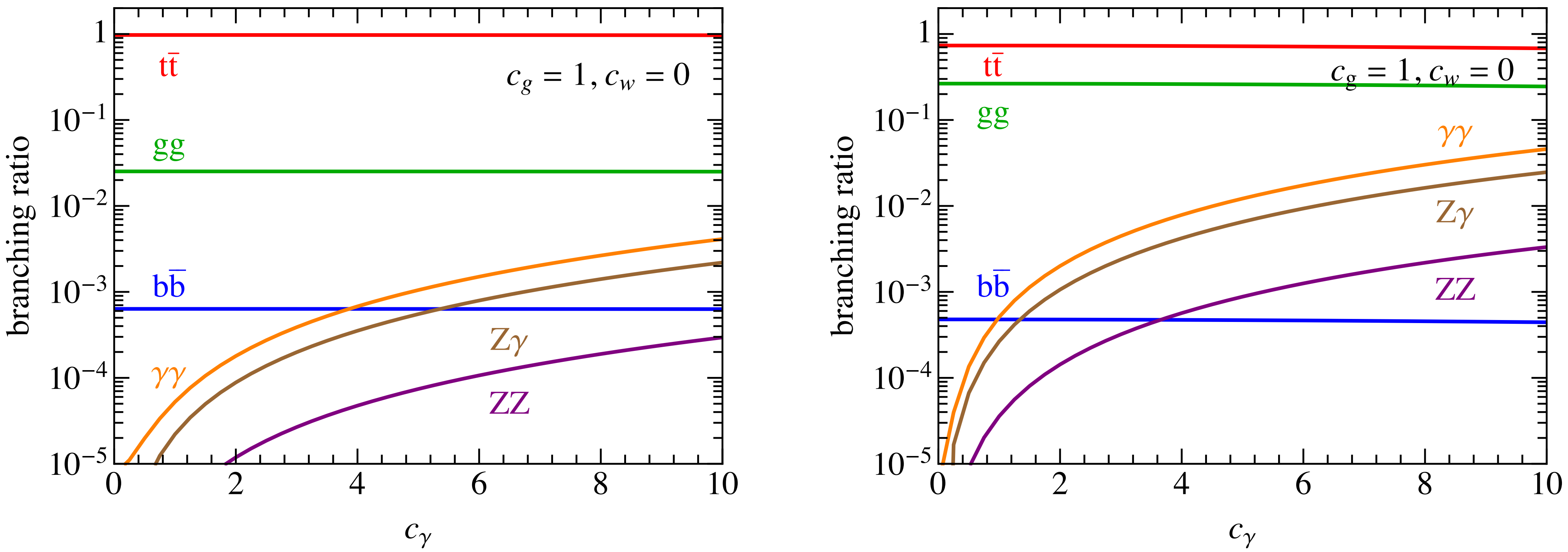


Can explain the excess

New QCD vs composite Higgs



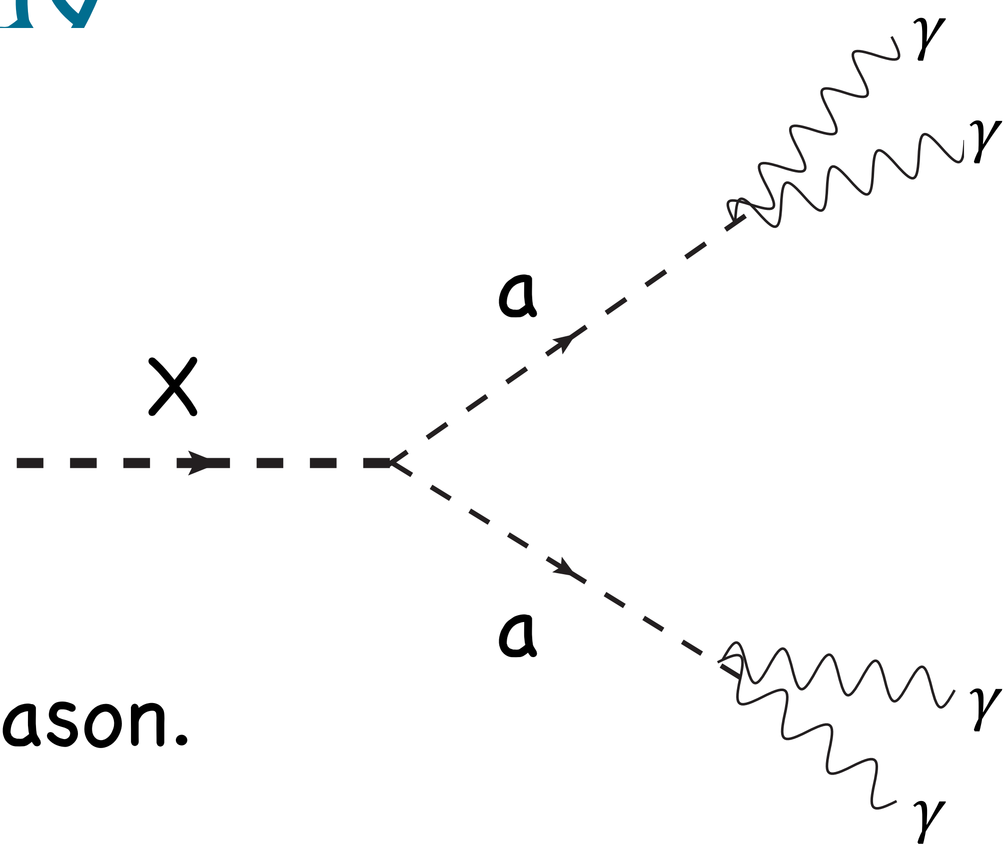
- The presence of ttbar.

- Presence of top-partner.

Alternative: 2-step decay

If $m_a << M_X \approx 750$ GeV,
LHC may not be able to resolve
the two photons.
So it could be a di-photon resonance.

May need $m_a <$ GeV. No compelling reason.
Life time of a challenging



Knapen et al
Strassler et al

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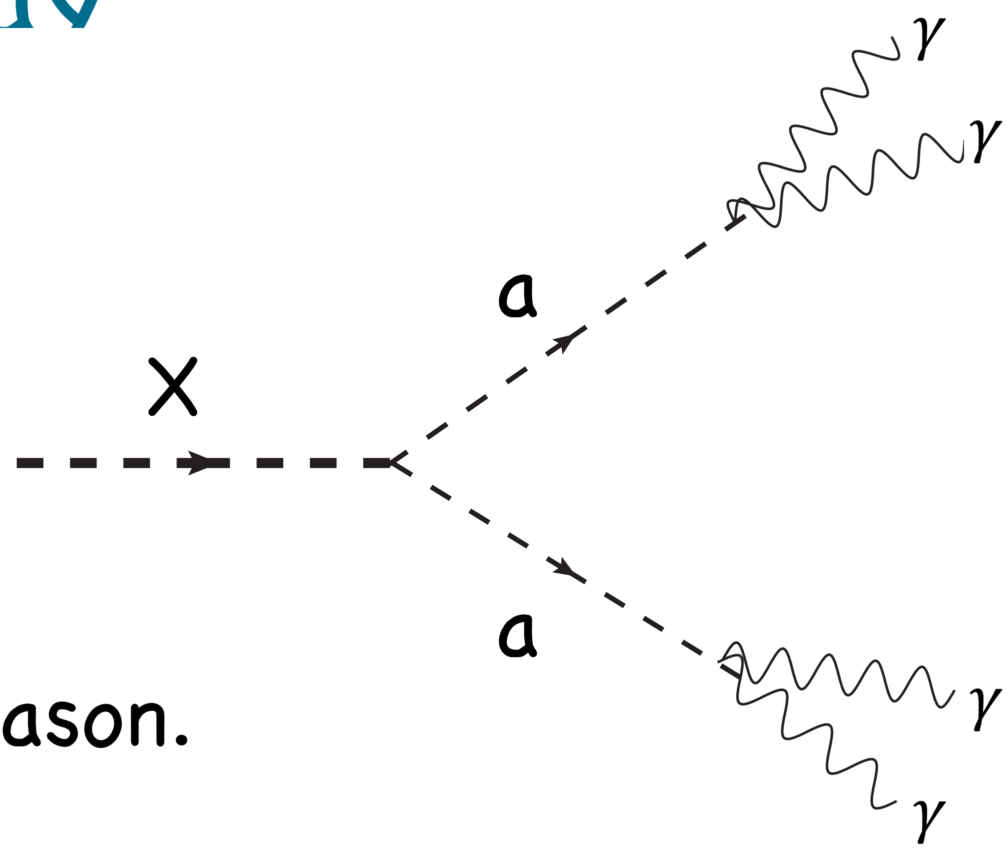


Knapen et al
Strassler et al

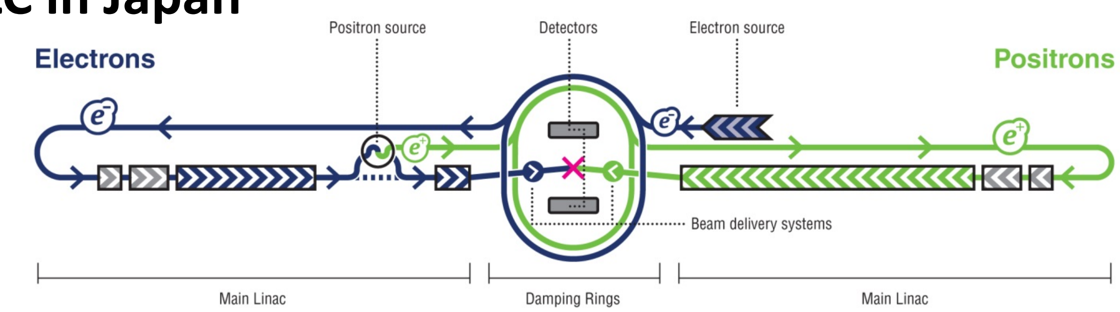
- Good "straw man" to test experimentally.
- Need a lot more new physics to complete the story.

Big picture

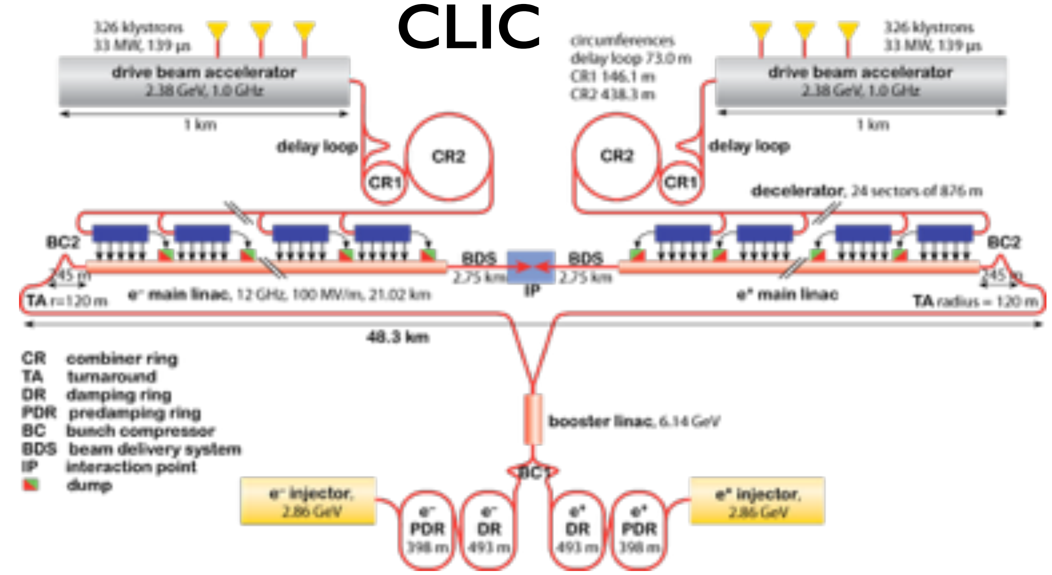
- Likely to be a (pseudo)scalar at 750 GeV.
- Large rate to di-photon. Need additional new physics!
  - Both charged and colored.
  - Perhaps around 500 GeV to TeV-ish, exact range model dependent.
- Looking good for being part of a natural theory.
  - New physics span over a decade of energy beyond TeV.

Beyond the LHC, future facilities

ILC in Japan



CLIC

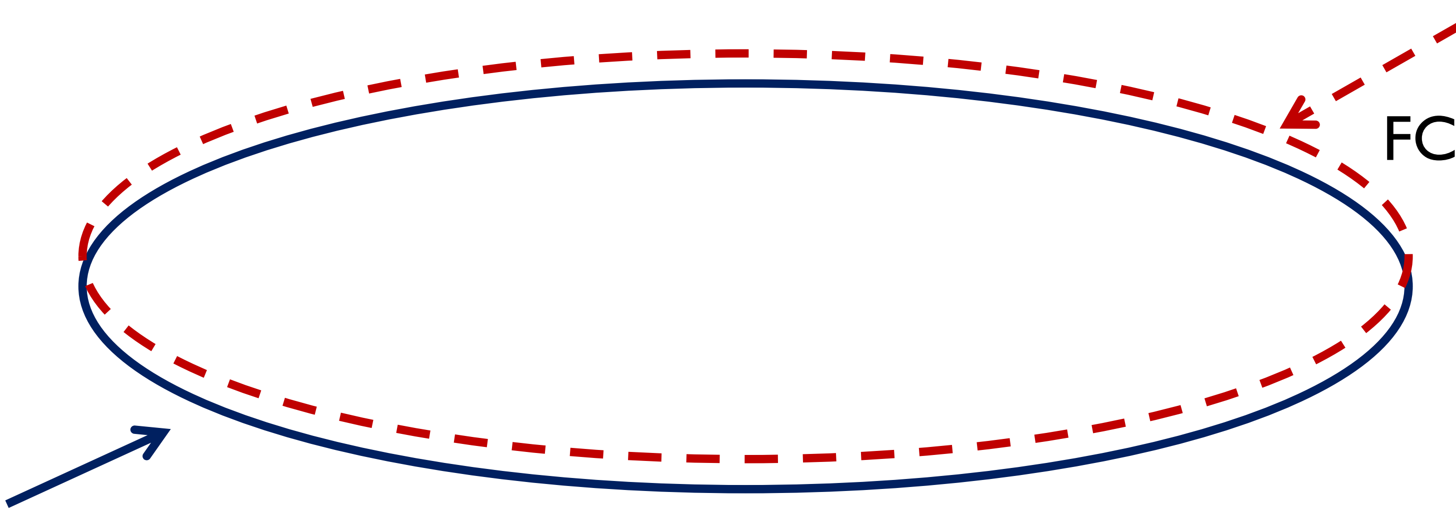


Circular. “Scale up” LEP+LHC

~100 TeV

pp collider

FCC-hh (CERN), SppC(China)



250 GeV **e^-e^+ Higgs Factory**

FCC-ee (CERN), CEPC(China)

Big ring ++

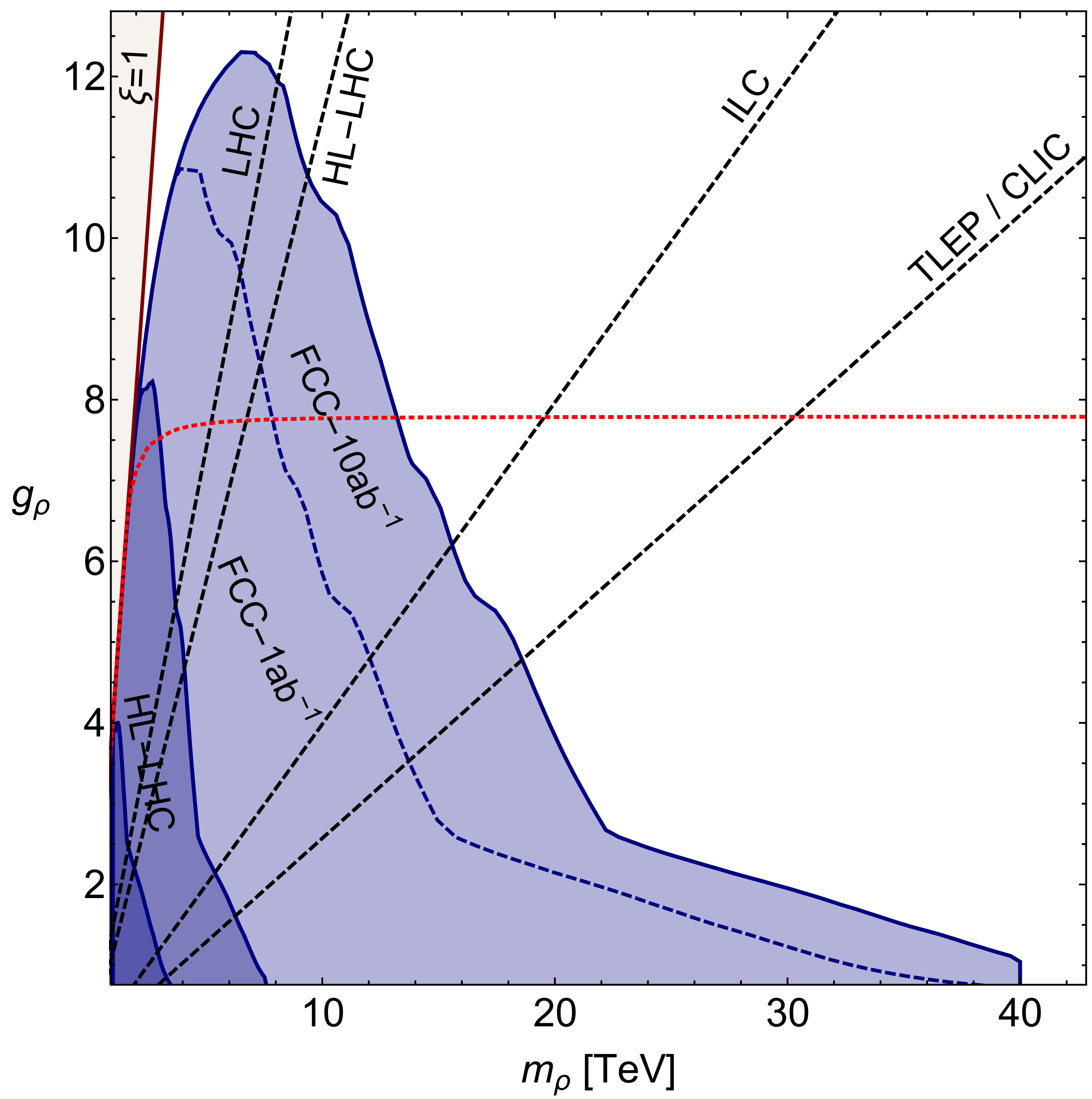
- The motivation for having a very large ring, with the goal of a super proton collider with higher energy (10s to 100 TeV), would be super strong.

  Completely unravel a new layer of new physics.

  Another 50+ years exciting discoveries.

- Lepton colliders, such as CLIC(to lesser extent the ILC), can cover some ground, especially the new charge particles. But unlikely the full story.

For example: composite Higgs



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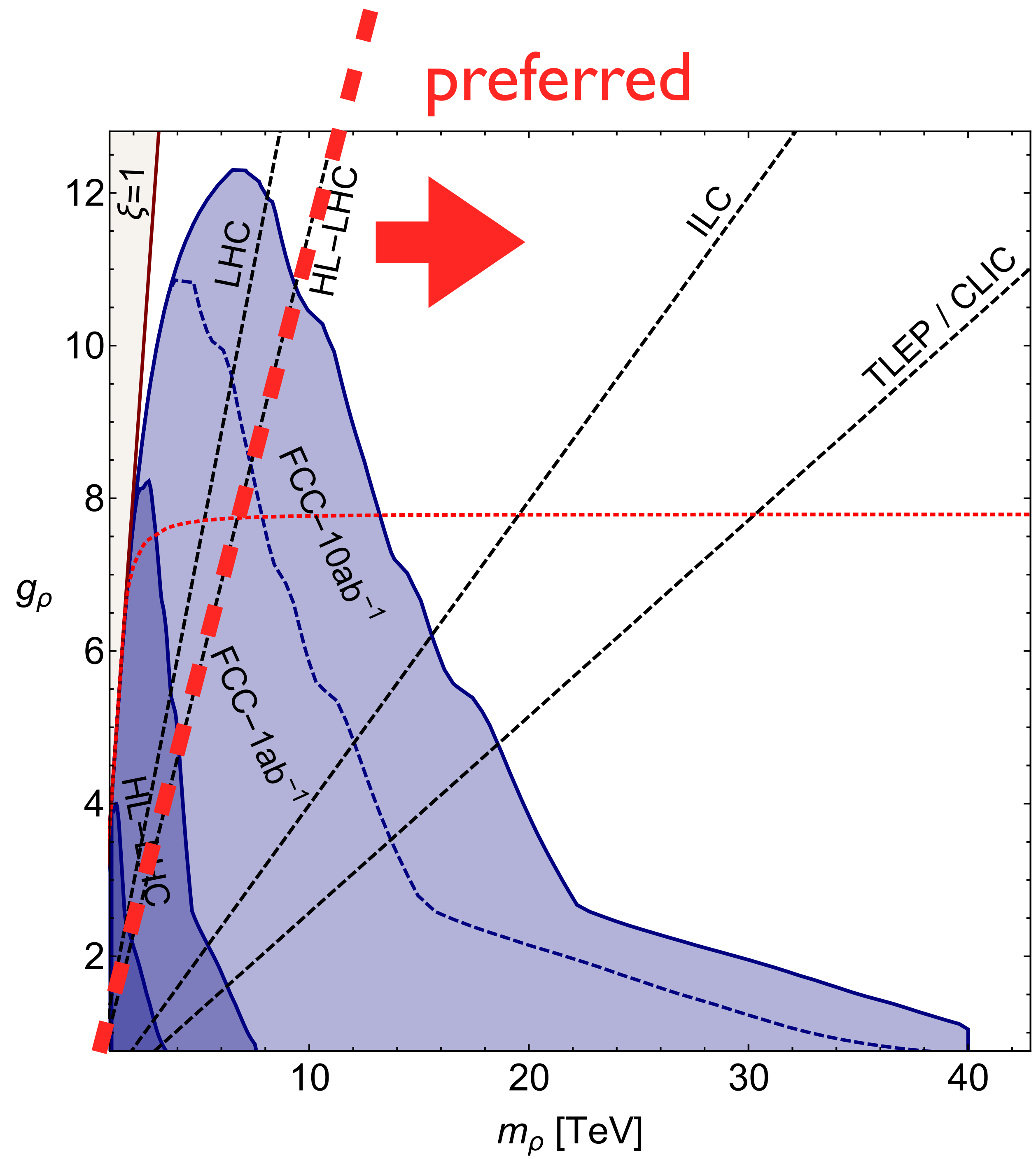

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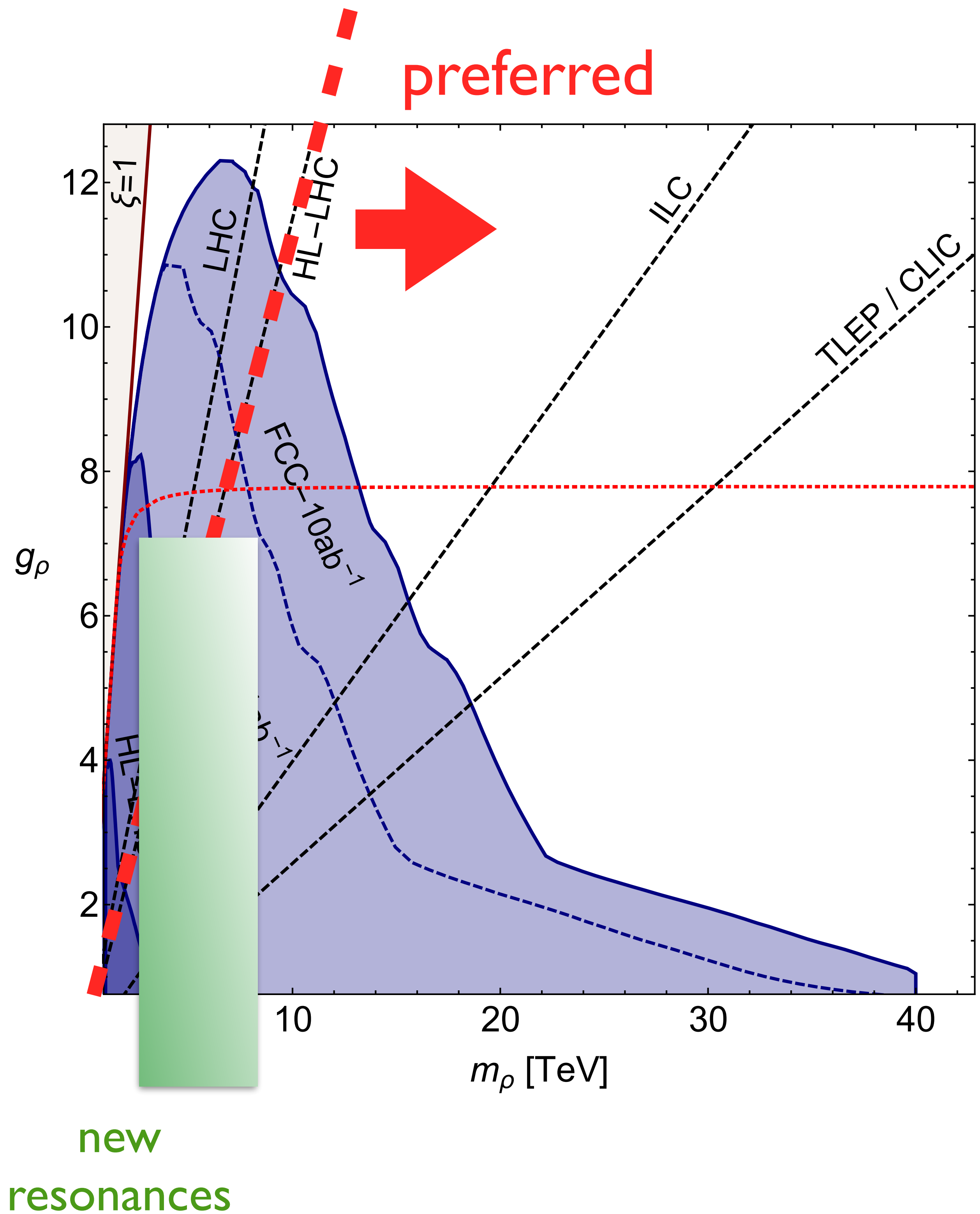

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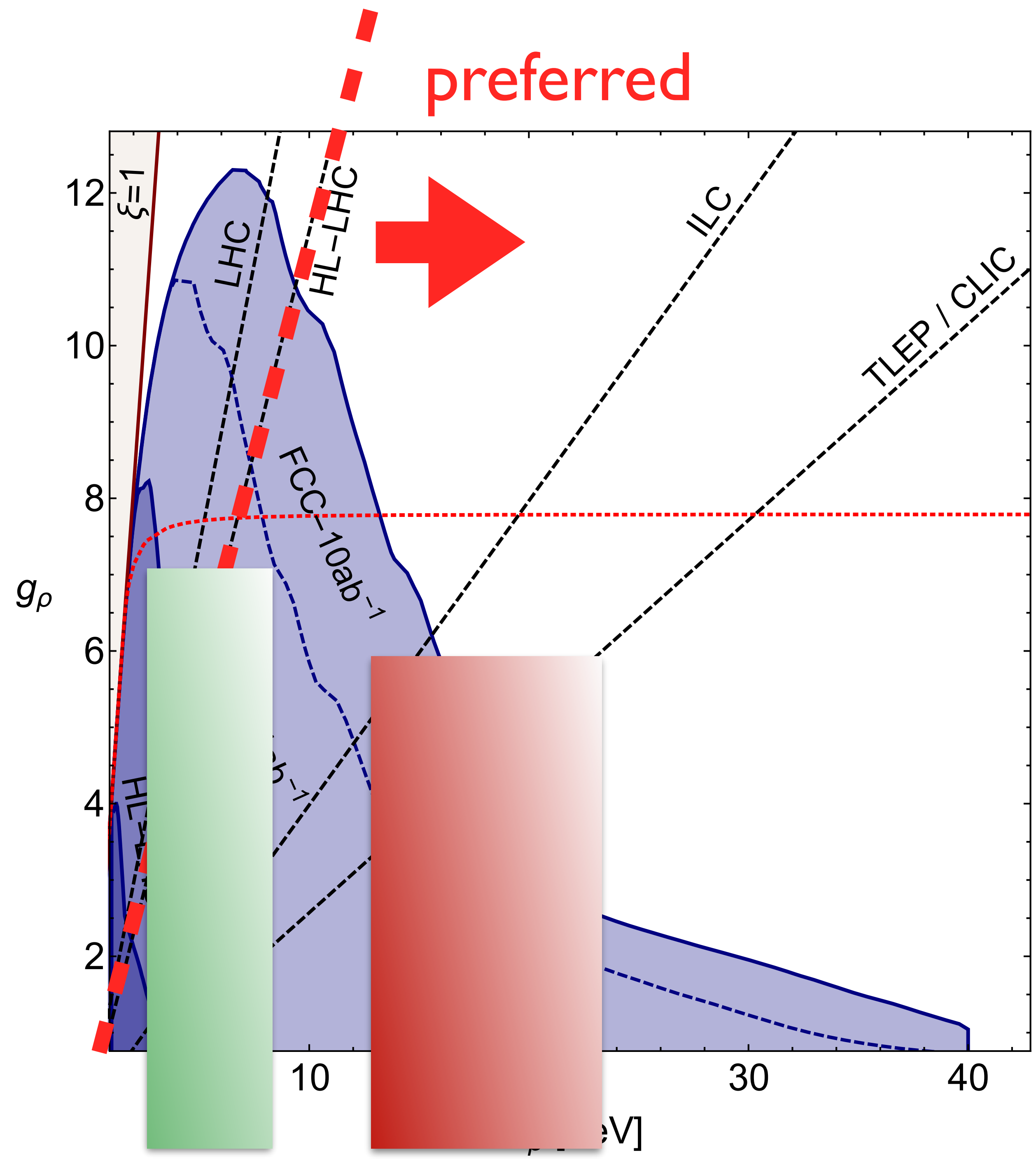

new resonances

new strong integration
new gluon and quarks